Ripple Morphology under Oscillatory Flow

Marcelo H. García
Ven Te Chow Hydrosystems Laboratory
Department of Civil and Environmental Engineering
University of Illinois at Urbana-Champaign
205 North Mathews Avenue
Urbana, Illinois 61801
phone: (217) 244-4484 fax: (217) 333-0687 email: mhgarcia@illinois.edu

Francisco Pedocchi
Ven Te Chow Hydrosystems Laboratory
Department of Civil and Environmental Engineering
University of Illinois at Urbana-Champaign
205 North Mathews Avenue
Urbana, Illinois 61801
phone: (217) 333-8365 fax: (217) 333-0687 email: pedocchi@illinois.edu

Blake J. Landry
Ven Te Chow Hydrosystems Laboratory
Department of Civil and Environmental Engineering
University of Illinois at Urbana-Champaign
205 North Mathews Avenue
Urbana, Illinois 61801
phone: (217) 333-8365 fax: (217) 333-0687 email: blandry2@illinois.edu

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LONG-TERM GOALS

Our ultimate long-term goal is to further the understanding of bed morphology and sediment dynamics under oscillatory flows. Experiments will be conducted to expand existing data sets of sand bed morphology and evolution in large scale laboratory facilities under controlled flow conditions. Based on this additional insight from the improved data set we aim to advance presently available tools for the prediction of sediment bed configuration.

OBJECTIVES

The main objective of this effort is to study the evolution and resulting final configuration of a uniform sand bed under various regular oscillatory flow forcings. In particular we would like to develop a

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robust dimensionless parametrization based on hydro- and sediment dynamics over the evolving ripple bed that gives understanding of the underyling physics controlling the occurrence of two or three dimensional ripples as well as the the development of various ripple types (e.g., orbital, suborbital, anorbital ripples, round crested ripples, etc). Furthermore, through this parametrization, we aim to establish better ripple predictors that can better determine the sand bed morphology for specified hydrodynamic conditions.

APPROACH

The research effort is primarily experimental, based on large scaled laboratory studies conducted in two distinctly different facilities: the Large Oscillatory Water Sediment Tunnel (LOWST) and the Large Wave Current Flume (LWCF). The experiments in the LOWST facility focus on the study of ripple morphodynamics under pure oscillatory flows. In this manner, the entire sediment test bed experiences the same fluid forcing on average, resulting in controlled uniform conditions, which in conjunction with the tunnel's 0.8 m width, makes the LOWST an ideal test environment from which to correlate the flow to resulting ripple morphologies. To further explore ripple dynamics, experiments in the LWCF focus on the spatial variations in ripples characteristics resulting from the surface waves forcing with the existence of finite reflection or directional spectrum composing the total wave field.

The research team is composed by Prof. Marcelo H. Garcia as PI and two PhD students, Francisco Pedocchi and Blake Landry as Co-PIs. Francisco Pedocchi is in charge of the experiments in the LOWST and Blake Landry is in charge of the experiments in the LWCF. Jose Maria Mier, also PhD student at the Hydrosystems Laboratory, participated in the experiments in the LOWST as well as a small oscillatory tunnel which is present in the laboratory.

WORK COMPLETED

New predictive tools for ripple wavelength, height and planform geometry at equilibrium morphologic conditions have been developed. These new predictors were initially inspired by our observations in the Large Oscillatory Water Sediment Tunnel (LOWST) at the Ven Te Chow Hydrosystems Laboratory, where we performed several experiments using quartz sand with D_{50} = 250 μm. The imposed water motions in the LOWST were sinusoidal oscillations which are completely symmetric thanks to its unique piston driver system. In most cases, the bed was flattened before each experiment. However, for some particular experiments concerning ripple evolution due to the change of the flow, the bed from a previous flow conditions was used. The details of the performed experiments can be found in Pedocchi and García 2009b (in press).

For the elaboration of the new predictors, along with our own data, an extensive data set compiled from the literature was used, covering a wide range of sediment and flow conditions. Twenty seven literature works reporting equilibrium ripples from both laboratory and field experiments, together with our own laboratory data were incorporated into the extensive database. The database included sediment, water, flow and ripple properties. A detailed description of the collected information can be found in Pedocchi and García 2009a (in press).

The performance of the ripple size predictors proposed by Nielsen (1981), Wiberg and Harris (1994), and Mogridge et al. (1994) was evaluated. All of them presented limitations to predict the compiled data. Nielsen (1981) predictor was the one performing best over the full range of conditions. However,

this is mostly due to the differentiation between field and laboratory conditions, which is not fully justified in the light of more recent experimental observations. This motivated the proposal of a new ripple size predictor, which does not differentiate between laboratory and field conditions. Regarding the prediction of the planform geometry of ripples, the criteria proposed by Carstens et al. (1969), Lofquist (1978), and Vongvisessomjai (1984) were evaluated with limited success and a new predictor was proposed.

To extend the work towards the cases in which surface waves result in spatial variability in the forcing, additional experiments were conducted in the LWCF coupled along with further analysis of an existing data set from the Parson Laboratory at MIT as documented by Landry (2004). This unique data set, which encompasses a range of wave conditions, provides the temporal/spatial evolution of bed morphology (i.e, both ripples and sandbars). Two evolutions ranges are recorded: high temporal resolution over smaller spatial domain (i.e., approximately one sandbar length which corresponds to half a water wavelength) as well as lower temporal resolutions (i.e., on the order of hours) documenting the sand bed over the entire sediment domain (roughly 15 to 20 meters) along the tank.

RESULTS

New experimental data on ripple morphology under oscillatory flow generated in the LOWST facility is now available. Including new planform geometry information that was not available before. Also the experiments in the LOWST have shown that for long water excursions the ripple size first decrease as the velociy increases but after a certain velocity is exceeded the ripples start to increase their size again, but now these ripples present round crests instead of the usual sharp crests. Anorbital ripples could not be generated in our experiments despite that we were well into the flow conditions that have been reported as necessary for their occurrence.

A new ripple size predictor has been proposed. It is based on recognizing local and global sediment transport mechanisms. Despite their complexity it was possible to obtain useful results by characterizing these two process scales with two dimensionless variables, $\mathbf{Re_p}$, a dimensionless particle size (Garcia 2008), and $U_{\max}/w_s$, the ratio between the maximum orbital velocity and the sediment settling velocity; and using the water excursion d to scale the ripple size λ. Figure 1 shows the performance of the predictor. The equations for the predictor and a complete description can be found in Pedocchi and García 2009a (in press).

A new planform geometry predictor has been proposed (Figure 2). It also highlights the importance of sediment size on the bed morphology and uses two dimensionless variables: the wave Reynolds number $\mathbf{Re_w} = U_{\max}A/\nu$, with A the amplitude of the near-bed water excursion, and the dimensionless sediment size $\mathbf{Re_p}$. Different behaviors were observed for coarse and fine sands. In general, for a given $\mathbf{Re_p}$ the ripple three-dimensionality increased with $\mathbf{Re_w}$. However, surprisingly anorbital ripples formed in fine sands tend to become more two-dimensional as the wave Reynolds number increases.

Also, a new friction factor expression that works for smooth, transitional, and rough oscillatory flows has been proposed (Figure 3). The new expression allows for better estimation of the Shield number for sands under oscillatory flows. A complete description can be found in Pedocchi and Garcia (2009).

In the case of free surface wave experiments conducted in wave tanks, the spatial variability of ripple characteristics was significantly influenced by wave reflection. It was found that even under low wave

reflection, e.g. 5%, a noticeable variation in ripple geometric characteristics is present in the sand bed as depicted with the variation of ripple wavelength in Figure 4. However, since the ripples are orbital, the present ripple predictors (including our newly proposed predictors) work well in estimating the ripple geometries using the computed near bed horizontal amplitude based on the wave measurements at each point along the tank. Even under high reflection cases (e.g. 90%) when the spatial variation in the wave field is pronounced and bar formation is substantial, the predictors still agree well to superimposed ripples geometries based on ripple measurements after subtracting the mean bed elevation from the total bed elevation. As seen in Figure 5, using the Wiberg and Harris (1994) predictor for reference, the ripple amplitude and wavelengths agree with the predictors even under this considerable variation in the surface wave envelope and the mean bed elevation. Refer to Landry et al. (2009) for more detailed information regarding these results.

IMPACT/APPLICATIONS

The new predictors are expected to provide better estimations of ripple morphology than what was previously available. In particular, the fact that anorbital ripples are not observed in coarse sands may have important implications when estimating bed roughness in wave propagation models. The results obtained also provide a better understanding of the possible bed configurations that can have a deep impact for geological interpretation of the strata preserved in sedimentary rocks as well as allowed for us to formulate a new dimensionless phase diagram (Figure 6). Finally, the results of this work should help also to identify particular aspects of the formation of ripples under oscillatory flow that deserve further study.

RELATED PROJECTS

This work is related to the past and present projects associated with the Mine Burial Effort on which our group has been participating, under the ONR Grants N00014-01-1-0337, and N00014-01-1-0540. Also the new equipment (PIV, LDV) purchased with the ONR Grant N00014-06-1-0661 (DURIP), is currently being used in the LOWST.

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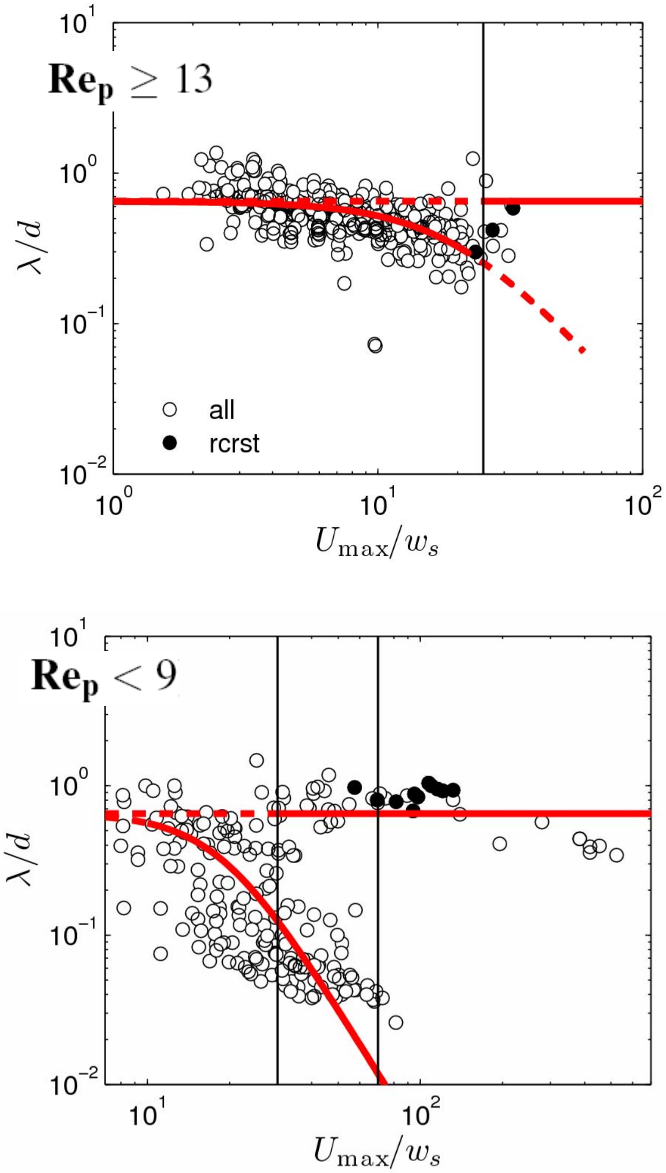

Figure 1: Performance of the new ripple size predictor, for coarse and fine sands.

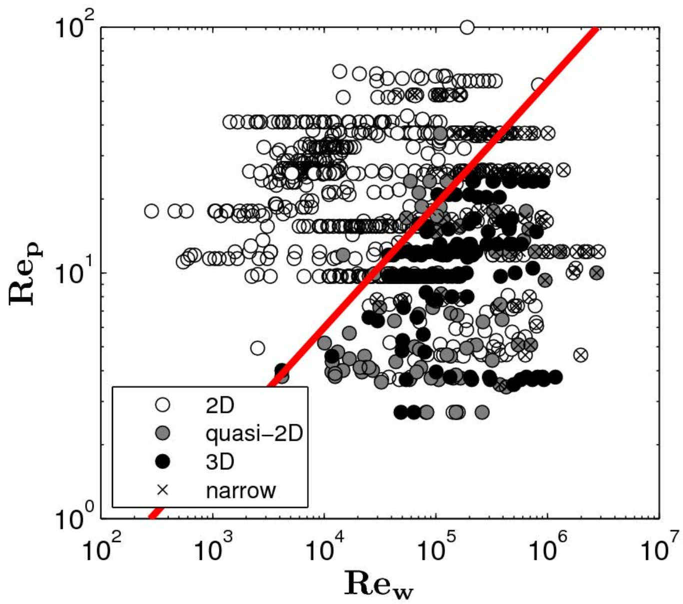

Figure 2: Performance of the new planform geometry predictor.

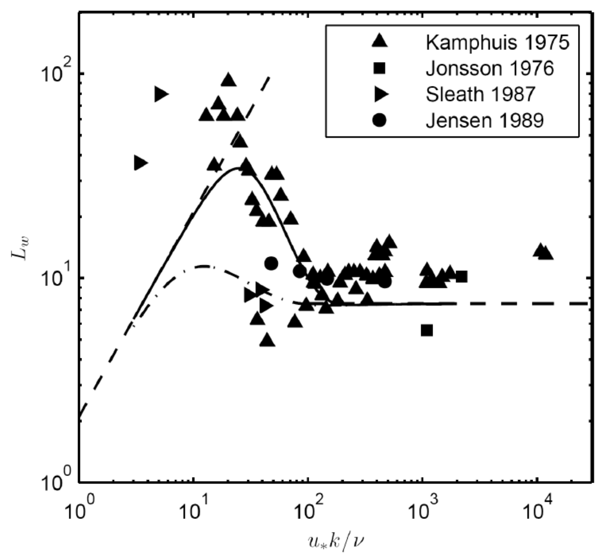

Figure 3: Transition from smooth to fully rough flow, the dash-dot line correspond to the transition equation usually assumed in unidirectional flows, the solid line corresponds to the newly proposed expression.

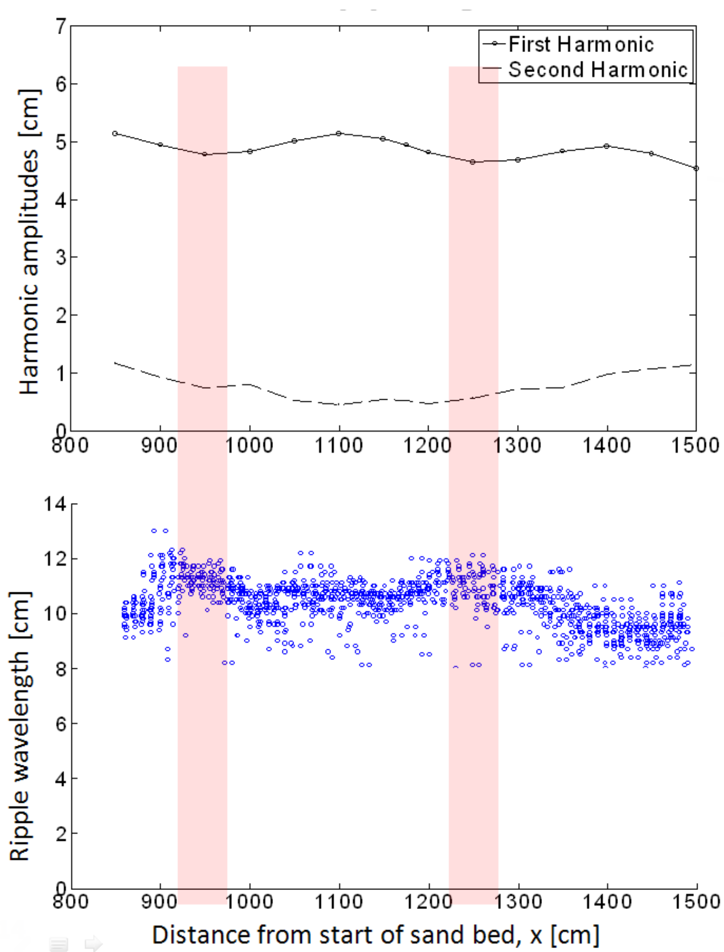

Figure 4: Variation of ripple wavelength measured in the LWCF under low reflection conditions of 5 % (incident amplitude of 5.1 cm wave period of 2.63 sec, and water depth of 60 cm). Top subplot: Harmonic amplitudes of the wave envelope along the tank; bottom subplot: ripple wavelength measurements based on 26 lateral transects along the length the sand bed.

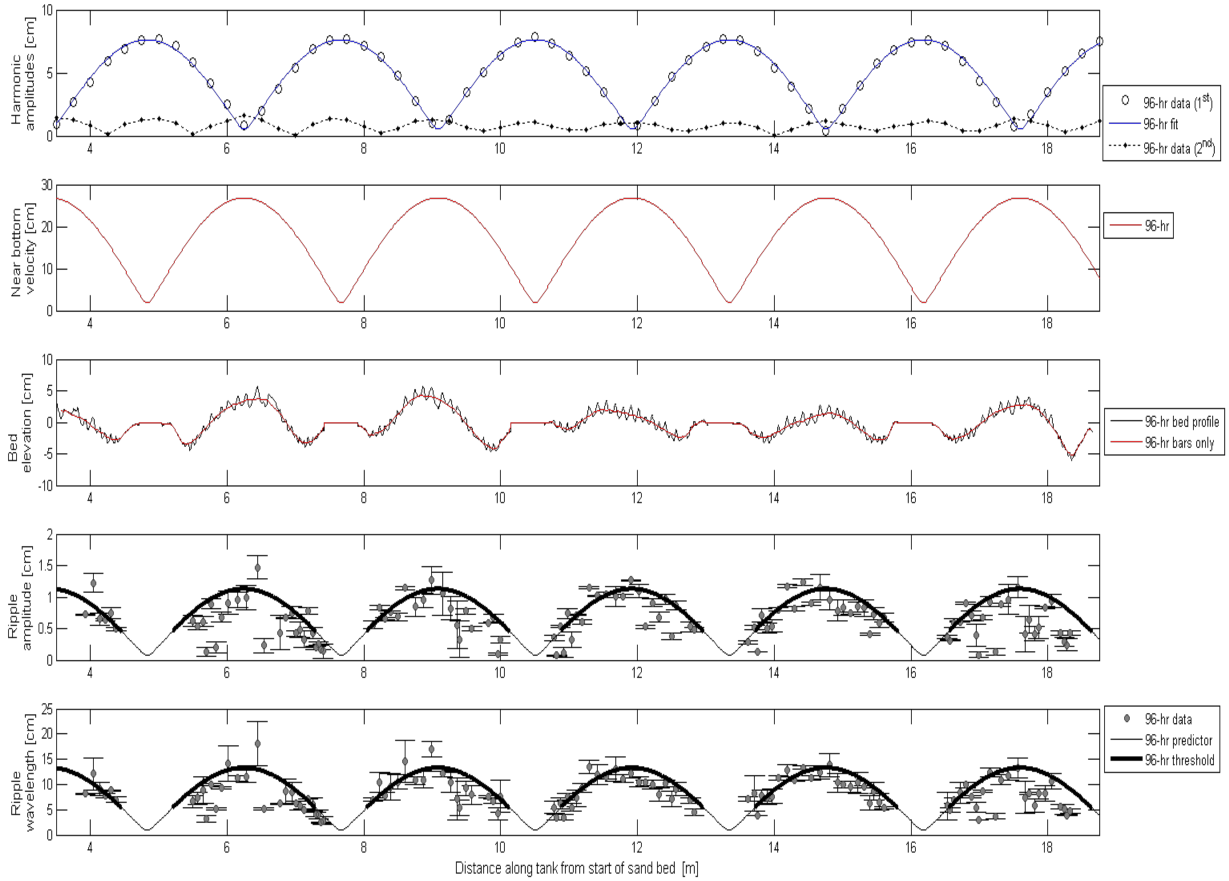

Figure 5: Analysis of high reflection (R = 0.88) experimental results after a 96-hr run duration. Subplot (a): depicts the measured first and second harmonic amplitudes along the entire sediment section represented Subplot (b): plots the computed maximum near-bed horizontal velocity based on fitting the wave measurements. Subplot (c): shows the complete sand bed profile (ripples and bars) with the smoother red line indicating the filtered "bar only" profiles. Subplot (d) and (e): illustrate the results for ripple amplitudes and wavelengths, respectively. The circle markers represent the mean measured ripple amplitude/wavelengths with error bars indicated the upper and lower corresponding estimates. For reference, the thin solid lines denote the geometric ripple predictor relations of Wiberg and Harris (1994), while the thick solid lines highlight the applicable regions of the ripple predictors accounting for necessary Shields stress conditions to initiate movement.

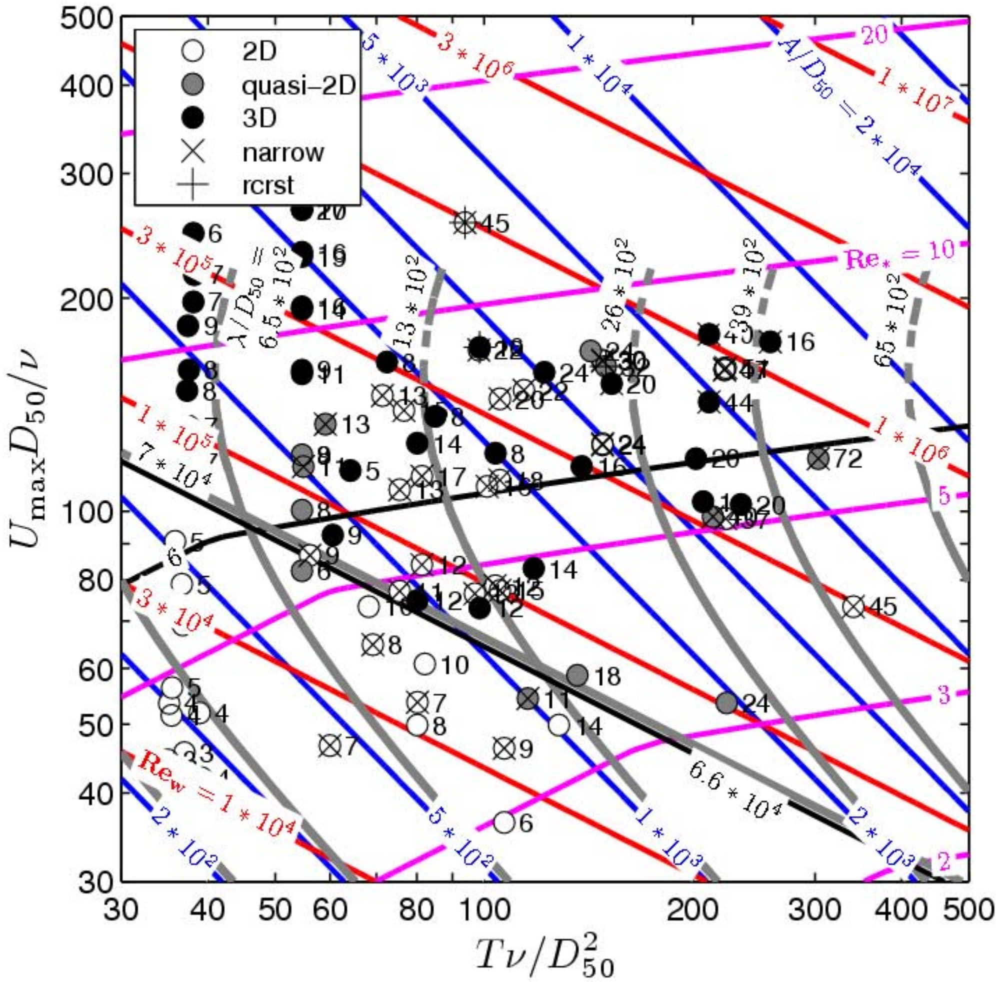

Figure 6: Dimensionless phase diagram for ripple morphology prediction. The numbers next to the symbols represent the dimensionless ripple wavelength λ/D_{50}. Diagram for $13<Re_p<24$.